CLAIMS

1. Tooling for working a structure to improve the fatigue strength at a selected location in said structure, said structure comprising a first surface, a second surface, and a body therebetween, said tooling comprising:

a first indenter, said first indenter comprising a contacting end for engagement with and deformation of a pre-selected portion of said first surface of said structure to impart a residual stress profile in said body of said structure,

and wherein said contacting end of said first indenter comprises a shaped surface profile substantially conforming to a dimple shape in said first surface of said structure produced by the application of a substantially uniform pressure profile on said pre-selected portion of said first surface of said structure,

and wherein said contacting end of said first indenter further comprises a surface shape defined by the equation:

$$u_z = \frac{C\,(4\,(1-v^2))}{E} P_m\, a \int_0^{\pi/2} \sqrt{1-\frac{q^2}{r^2}(\sin^2\theta)}\; d\theta$$

wherein

u_z =normal displacement of a selected surface location of said contacting end of said indenter above a flat reference plane,

v=Poisson's Ratio of the material comprising said workpiece;

E=Elastic Modulus of the material comprising said workpiece;

P_m = contact pressure distribution that yields said workpiece ;

a=radius of the contacting end of said indenter; and

θ, r = polar coordinates of a selected surface location on said contacting end of said indenter.

C = a constant ranging from 1 to 110.

2. Tooling as set forth in claim 1, further comprising a second indenter, said second indenter comprising a contacting end for engagement with and deformation of a pre-selected portion of said second surface of said structure to impart a residual stress profile in said body of said structure, and wherein said contacting end of said second indenter comprises a surface shape substantially conforming to a dimple shape in said second surface of said structure produced by the application of a substantially uniform profile on said pre-selected portion of said second surface of said structure, wherein said contacting end of said second indenter further comprises a surface shape defined by the equation:

$$u_z = \frac{C\,(4\,(1-v^2))}{E} P_m\, a \int_0^{\pi/2} \sqrt{1-\frac{a^2}{r^2}(\sin^2\theta)}\; d\theta$$

u_z =normal displacement of a selected surface location of said contacting end of said indenter above a flat reference plane;

v=Poisson's Ratio of the material comprising said workpiece;

E=Elastic Modulus of the material comprising said workpiece;

P_m = contact pressure distribution that yields said workpiece;

a = radius of the contacting end of said indenter;

θ, r = polar coordinates of a selected surface location on said contacting end of said indenter, and

C = a constant from about 1 to about 110.

3. Tooling as set forth in claim 1, wherein said first indenter further comprises a downwardly projecting centering punch portion.

4. Tooling as set forth in claim 2, wherein said second indenter further comprises a downwardly projecting centering punch portion.

5. Tooling as set forth in claim 1, wherein said first indenter comprises a dynamic indenter, said dynamic indenter adapted for engagement of said shaped surface of said contacting end against said first surface of said structure.

6. Tooling as set forth in claim 1, wherein said second indenter comprises a second dynamic indenter, said second dynamic indenter adapted for engagement of said shaped surface of said contacting end against said second surface of said structure.

7. An apparatus for treating material bounding the location selected for creation of an opening in a workpiece, in order to provide beneficial residual stress in material bounding said opening, to thereby improve fatigue life of said workpiece, said apparatus comprising:

a support structure, said support structure adapted to securely support a workpiece;

a shaped indenter having a contacting end; and

a dynamic indenter driver, said dynamic indenter driver adapted to drive said contacting end of said shaped indenter into a pre-selected surface portion of

said workpiece at a velocity sufficient to cause formation of a stress wave in said workpiece in reaction to the action of said contacting end of said shaped indenter; and

wherein said contacting end of said shaped indenter further comprises a surface shape defined by the equation:

$$u_z = \frac{C\,(4\,(1-v^2))}{E} P_m\, a \int_0^{\pi/2} \sqrt{1-\frac{a^2}{r^2}(\sin^2\theta)}\; d\theta$$

wherein

u_z =normal displacement of a selected surface location of said contacting end of said indenter above a flat reference plane;

v=Poisson's Ratio of the material comprising said workpiece;

E=Elastic Modulus of the material comprising said workpiece;

P_m = contact pressure distribution that yields said workpiece;

a=radius of the contacting end of said indenter;

θ,r = polar coordinates of a selected surface location on said contacting end of said indenter, and

C = a constant from about 1 to about 110.

8. The apparatus as set forth in claim 7, further comprising an anvil, said anvil positioned in a firm backing relationship with said workpiece, said workpiece comprising an obverse and a reverse side, so that when said indenter acts on said obverse side of said workpiece, said reverse side of said workpiece is substantially supported by said anvil against movement in the direction of impact of said indenter.

9. The apparatus as set forth in claim 7, further comprising a second indenter and a second indenter driver, and an indenter driver controller, and wherein said first indenter driver and said second indenter driver are responsive to said indenter driver controller to simultaneously impact an obverse side and a reverse side of said workpiece, respectively.

10. The apparatus as set forth in claim 9, wherein said first indenter further comprises a pilot alignment guide, and wherein said second indenter further comprises a pilot alignment guide receiving portion, said pilot guide disposed through said workpiece for close interfitting engagement with said pilot guide receiving portion of said second indenter, so that during impact of said workpiece by said first indenter and said second indenter, said pilot alignment guide is received by said pilot guide alignment receiving portion.

11. The apparatus as set forth in claim 8, wherein said anvil further comprises a pilot alignment guide, and wherein said first indenter further comprises a pilot alignment guide receiving portion, said pilot guide disposed through said workpiece for close interfitting engagement with said pilot guide receiving portion of said first indenter, so that during impact of said workpiece by said first indenter, said pilot alignment guide is received by said pilot alignment guide receiving portion.

12. The apparatus as set forth in claim 7, further comprising at least one a deformable, consumable lamina disposed between said first indenter and said

pre-selected surface portion of said workpiece, and wherein said consumable lamina comprises an obverse side and a reverse side, and wherein said obverse side is acted upon by said first indenter.

13. The apparatus as set forth in claim 7, further comprising a second deformable, consumable lamina disposed between said second indenter and a second pre-selected surface portion of said workpiece, and wherein said consumable lamina comprises an obverse side and a reverse side, and wherein said obverse side is acted upon by said second indenter.

14. The apparatus as set forth in claim 12 or in claim 13, wherein said obverse side of said consumable lamina further comprises a lubricant, said lubricant adapted to decrease friction between said first or said second indenter and said obverse side of said lamina.

15. The apparatus as set forth in claim 14, wherein said lubricant comprises a dry film lubricant.

16. A method of manufacturing a joint which includes overlapping at least first and second structural members, said method comprising:

(a) contacting a preselected portion of said first structural member with an indenter having a contacting end at a pressure greater than the yield point of the composition of said first structural member to deform a portion of said first structural member in a manner so as to impart a pre-selected residual stress at a location at or near a selected location for a first fastener aperture through said

first structural member, and wherein said residual compressive stress is substantially uniform along the entire length of sidewall portions of said first fastener aperture and wherein said contacting end of said indenter comprises a shaped surface profile substantially conforming to a dimple shape in said pre-selected portion of said first structural member produced by the application of a pressure profile that provides an effective amount of beneficial residual compressive stress in said pre-selected portion of said first structural member;

(b) machining said first structural member to define said first fastener aperture via sidewall portions resulting from said machining;

(c) providing in said second structural member, a second fastener aperture defined by second sidewall portion; and

(d) inserting a fastener through said first and said second fastener apertures.

17. The method of claim 16, further comprising the step of applying force to said fastener to seat said fastener within said first and said second fastener apertures.

18. The method of claim 17, wherein the step of seating said fastener further comprises deforming an end portion of said fastener in order to secure and retain said fastener against said first structural member.

19. A joint comprising:

(a) a stack of structural members including

(1) a first member having a body made of material in which a first fastener aperture defined by a first edge wall portion is conditioned to have a residual compressive stress, wherein said conditioning is accomplished by a method comprising

(A) providing an indenter, said indenter comprising a surface portion, said surface portion adapted to impact said first member at pre-selected surface location adjacent said pre-selected location for said first fastener aperture in said structure,

(B) indenting said pre-selected surface location of said first member to provide a pre-selected amount of residual stress in said first member within said bounding portion of material; and

(C) wherein said contacting surface portion of said indenter comprises a shaped surface profile that provides an effective amount of beneficial residual compressive stress at or near said pre-selected surface location of said first member, and

(2) a second member having a second fastener aperture defined by a second edge wall portion, said second fastener aperture aligned with said first fastener aperture;

(b) an interference fit fastener including a shank portion, said shank portion located adjacent said first fastener aperture and adjacent said second fastener aperture, and wherein said first fastener aperture provides residual compressive stresses around said shank portion.

20. The joint as set forth in claim 19, wherein said interference fit fastener comprises a flush type rivet further comprising a countersunk portion, and

wherein said residual compressive stress is applied through said body of said first member along said countersunk portion of said rivet.

21. The joint as set forth in claim 19, wherein said interference fit fastener comprises a rivet having a straight shank portion, and wherein said residual compressive stress is applied substantially uniformly through said body of said first member along said first edge wall portion.

22. A joint comprising;

(a) a stack of structural members including

(1) a first member having a body made of material in which a first fastener aperture defined by a first edge wall portion on that is conditioned to have a residual compressive stress by a method of working a bounding portion of material in said first member, wherein the bounding portion is adjacent a pre-selected location for an opening in said first member, in order to provide residual compressive stresses in said bounding portion for improving the fatigue life of said first member, wherein said method of working comprises

(A) providing an indenter, said indenter comprising a surface portion, said surface portion adapted to impact said first member at pre-selected surface location adjacent said pre-selected location for said first fastener aperture in said structure,

(B) indenting said pre-selected surface location of said first member to provide a pre-selected amount of residual stress in said first member within said bounding portion of material; and

(C) wherein said contacting surface portion of said indenter comprises a shaped surface profile that provides an effective amount of beneficial residual compressive stress at or near said pre-selected surface location of said first member, and

(2) a second member having a second fastener aperture defined by a second edge wall portion, said second fastener aperture aligned with said first fastener aperture;

(b) a fastener, said fastener securely affixing said first member to said second member.

23. The joint as set forth in claim 19 or in claim 22, wherein said second member comprises a second fastener aperture having a second edge wall portion, and wherein said second edge wall portion is conditioned to have residual compressive residual stress, and wherein said residual compressive stress is provided by a method of working of a bounding portion of material in said second member, wherein said bounding portion is adjacent a pre-selected location for an opening in said second member, in order to provide residual compressive stresses in said bounding portion for improving the fatigue life of said second member, and wherein said method of working said bounding portion in said second member comprises

(A) providing an indenter, said indenter comprising a surface portion , said surface portion adapted to impact said second member at pre-selected surface location adjacent said pre- selected location for a second fastener aperture in said structure,

(B) indenting said pre-selected surface location of said second member to provide a pre-selected amount of residual stress in said second member within said bounding portion of material; and

(C) wherein said contacting surface portion of said indenter comprises a shaped surface profile that provides an effective amount of beneficial residual compressive stress in said structure at or near said pre-selected surface location of said second member, and (2) wherein said second fastener aperture in said second member is aligned with said first fastener aperture in said first member.

24. The joint as set forth in claim 23, wherein said joint further comprises a third member, and wherein said third member comprises a third aperture defined by a third edge wall portion, and wherein said third edge wall portion is conditioned by the method of claim 1, so as to have beneficial residual compressive stress.

25. Tooling for working a structure to improve the fatigue strength at a selected location in said structure, said structure comprising a first surface, a second surface, and a body therebetween, said tooling comprising:

a first indenter, said first indenter comprising a contacting end for engagement with and deformation of a pre-selected portion of said first surface and said body of said structure to impart a beneficial residual stress profile in said surface and in said body of said structure,

and wherein said contacting end of said first indenter comprises a pre-selected shaped surface profile for imparting a pre-selected dimple shape in said first surface and said body of said structure.

26. Tooling as set forth in claim 25, further comprising a second indenter, said second indenter comprising a contacting end for engagement with and deformation of a pre-selected portion of said second surface of said body of said structure to impart a pre-selected residual stress profile in said surface and in said body of said structure, and wherein said contacting end of said second indenter comprises a pre-selected shaped surface profile for imparting a pre-selected dimple shape in said second surface and said body of said structure.

27. Tooling as set forth in claim 25, wherein said first indenter further comprises a downwardly projecting centering punch portion for creating a centering feature in said first surface.

28. Tooling as set forth in claim 26, wherein said second indenter further comprises a downwardly projecting centering punch portion for creating a centering feature in said first surface.

29. Tooling as set forth in claim 25, wherein said first indenter comprises a dynamic indenter, said dynamic indenter adapted for engagement of said shaped surface of said contacting end against said first surface of said structure.

30. Tooling as set forth in claim 25, wherein said second indenter comprises a second dynamic indenter, said second dynamic indenter adapted for

engagement of said shaped surface of said contacting end against said second surface of said structure.

31. An apparatus for treating material bounding the location selected for creation of an opening in a workpiece, said workpiece having an obverse and a reverse side, in order to provide beneficial residual stress in material bounding said opening, to thereby improve fatigue life of said workpiece, said apparatus comprising:

a support structure, said support structure adapted to securely support a workpiece;

a shaped indenter having a contacting end; and

a first indenter driver, said first indenter driver adapted to drive said contacting end of said shaped indenter into a pre-selected surface portion of said workpiece; and

wherein said contacting end of said shaped indenter further comprises a surface shape that provides a pre-selected residual stress profile to said workpiece.

32. The apparatus as set forth in claim 31, further comprising an anvil, said anvil positioned in a firm backing relationship with said workpiece, so that when said indenter acts on said obverse side of said workpiece, said reverse side of said workpiece is substantially supported by said anvil against movement in the direction of motion of said indenter.

33. The apparatus as set forth in claim 31, further comprising a second indenter and a second indenter driver, and an indenter driver controller, and wherein said first indenter driver and said second indenter driver are responsive to said indenter driver controller to simultaneously impact an obverse side and a reverse side of said workpiece, respectively.

34. The apparatus as set forth in claim 33, wherein said first indenter further comprises a pilot alignment guide, and wherein said second indenter further comprises a plot alignment guide receiving portion, said pilot guide disposed through said workpiece for close interfitting engagement with said pilot guide receiving portion of said second indenter, so that during impact of said workpiece by said first indenter and said second indenter, said pilot alignment guide is received by said pilot guide alignment receiving portion.

35. The apparatus as set forth in claim 32, wherein said anvil further comprises a pilot alignment guide, and wherein said first indenter further comprises a pilot alignment guide receiving portion, said pilot guide disposed through said workpiece for close interfitting engagement with said pilot guide receiving portion of said first indenter, so that during impact of said workpiece by said first indenter, said pilot alignment guide is received by said pilot alignment guide receiving portion.

36. Tooling for working a structure to improve the fatigue strength at a selected location in said structure, said structure comprising a first surface, a second surface, and a body therebetween, said tooling comprising:

a first indenter, said first indenter comprising a contacting end for engagement with and deformation of a pre-selected portion of said first surface of said structure to impart a residual stress profile in said body of said structure,

and wherein said contacting end of said first indenter comprises a shaped surface profile substantially conforming to a dimple shape in said first surface of said structure produced by the application of a substantially uniform pressure profile on said pre-selected portion of said first surface of said structure.

37. Tooling as set forth in claim 36, wherein said first indenter comprises a dynamic indenter, said dynamic indenter adapted for engagement of said shaped surface of said contacting end against said first surface of said structure.

38. Tooling as set forth in claim 36, further comprising a backing anvil, said backing anvil adapted to firmly support said structure when said structure is subjected to engagement by said indenter, so that movement of said structure is substantially prevented in the direction of action on said structure by said dynamic indenter.

39. Tooling as set forth in claim 36, further comprising a second indenter, said second indenter comprising a contacting end for engagement with and deformation of a pre-selected portion of said second surface of said structure to impart a residual stress profile in said body of said structure, and wherein said contacting end of said second indenter comprises a surface shape substantially conforming to a dimple shape in said second surface of said structure produced

by the application of a substantially uniform pressure profile on said pre-selected portion of said second surface of said structure.

40. Tooling as set forth in claim 39, wherein said second indenter comprises a second dynamic indenter, said second dynamic indenter adapted for engagement of said shaped surface of said contacting end against said second surface of said structure.

41. Tooling as set forth in claim 39, wherein said first indenter and said second indenter are of unequal cross-sectional area.

42. Tooling as set forth in claim 37, wherein said first indenter leaves a footprint shape in response to engagement of said contacting end against said structure, and wherein said footprint shape is substantially circular.

43. Tooling as set forth in claim 37, wherein said first indenter leaves a footprint shape in response to engagement of said contacting end against said structure, and wherein said footprint shape is non-circular.

44. Tooling as set forth in claim 40, wherein said second indenter leaves a footprint shape in response to engagement of said contacting end against said structure, and wherein said footprint shape is substantially circular.

45. Tooling as set forth in claim 40, wherein said second indenter leaves a footprint shape in response to engagement of said contacting end against said structure, and wherein said footprint shape is non-circular.

46. A method for working a bounding portion of material in a structure, said structure comprising two or more workpieces, said bounding portion adjacent a pre-selected location for an opening in said structure, in order to provide residual compressive stresses in said bounding portion for improving the fatigue life of said structure, said method comprising:

providing an indenter, said indenter comprising a surface portion, said surface portion adapted to impact said structure at pre-selected surface locations adjacent said pre-selected location for said opening in said structure;

indenting said pre-selected surface location of said structure to provide a pre-selected amount of residual stress in said structure within said bounding portion of material.

47. The method as set forth in claim 46, further comprising removal of a selected portion of material from said structure, said selected portion of material removed from said structure having an outer border portion, said outer border portion located at or adjacent to said pre-selected surface location on said structure having been impacted by said shaped surface portion of said indenter.

48. The method as set forth in claim 46, wherein said indenter comprises a dynamic indenter.

49. The method as set forth in claim 46, wherein said opening comprises an elongated recessed portion.

50. The method as set forth in claim 47, wherein said opening comprises a through passageway.

51. The method as set forth in claim 47, wherein said elongated recessed portion further comprises a closed end portion.

52. The method as set forth in claim 47, wherein said indenter comprises a shaped indenter surface portion, said shaped indenter surface portion providing, when impacted on said workpiece at a pre-selected velocity, a pre-selected amount of permanent deformation in said workpiece sufficient to produce a shaped surface portion in said workpiece corresponding to that shape formed by indenting said pre-selected location in such workpiece material with a uniform pressure profile, and wherein said uniform pressure profile over said pre-selected location is at least as large as the yield stress pressure in said material.

53. The method as set forth in claim 47, wherein said surface portion comprises a flat surface portion.

54. A joint comprising:

(a) a stack of structural members including

(1) a first member having a body made of material in which a first fastener aperture defined by a first edge wall portion is conditioned to have a residual compressive stress, and

(2) a second member having a second fastener aperture defined by a second edge wall portion, said second fastener aperture aligned with said first fastener aperture;

(b) an interference fit fastener including a shank portion, said shank portion located adjacent said first fastener aperture and adjacent said second fastener aperture, and wherein said first fastener aperture provides residual compressive stresses around said shank.

55. The joint as set forth in claim 54, wherein said interference fit fastener comprises a flush type rivet further comprising a countersunk portion, and wherein said residual compressive stress is applied through said body of said first member along said countersunk portion of said rivet.

56. The joint as set forth in claim 55, wherein said interference fit fastener comprises a rivet having a straight shank portion, and wherein said residual compressive stress is applied substantially uniformly through said body of said first member along said first edge wall portion.

57. A method for working a bounding portion of material adjacent a preselected location for an opening in the body of a workpiece, to create beneficial residual compressive stress in said bounding portion for improving the fatigue life of said workpiece, said method comprising:

providing an indenter, said indenter comprising a surface portion, said surface portion adapted to impact said workpiece at pre-selected surface locations adjacent said pre-selected location for said opening in said workpiece;

indenting the body of said workpiece at said pre-selected surface location of said workpiece with said indenter to provide an effective amount of beneficial residual stress compressive stress in said structure within at least a portion of said bounding portion of material in said body of said workpiece;

removing from said body of said workpiece a selected portion of material, said selected portion of material removed to define a bounding portion adjacent an opening created by removal of said material, said material removed comprising at least a portion of said workpiece having been impacted by said shaped surface portion of said indenter, so that at least a portion of said bounding portion of said body of said workpiece material expands toward said opening.

58. The method as set forth in claim 57, wherein said opening comprises an elongated recessed portion.

59. The method as set forth in claim 58, wherein said elongated recessed portion further comprises a closed end portion.

60. The method as set forth in claim 57, wherein said opening comprises a through passageway.

61. The method as set forth in claim 57, wherein preselected surface location portion comprises a flat surface location.

62. The method as set forth in claim 57, wherein said workpiece comprises a section of non-uniform thickness.

63. The method as set forth in claim 57, wherein said workpiece is of uniform thickness in cross-section.

64. The method as set forth in claim 57, further comprising the step of providing an external support behind said workpiece prior to the step of indenting said workpiece, said external support positioned in a firm backing relationship with said workpiece, so that when said indenter acts on said workpiece, said workpiece is substantially supported by said external support against movement in a direction normal to the direction of impact of said indenter.

65. The method as set forth in claim 57, wherein said workpiece comprises an interior through passageway defined by an interior edge wall, and wherein the method further comprises the step of providing an internal support adjacent said interior edge wall to resist deformation of said workpiece during the step of indenting said workpiece.

66. The method as set forth in claim 57, wherein said workpiece comprises an interior through passageway defined by an interior edge wall, and wherein after

the step of indenting said workpiece, the method further comprises the step of trimming a portion of said workpiece adjacent said interior edge wall.

67. The method as set forth in claim 57, wherein said workpiece comprises a plurality of locations at which openings are to be placed, and wherein the step of indenting said workpiece is performed at said each of said locations simultaneously.

68. The method as set forth in claim 57, wherein said workpiece comprises a plurality of locations at which openings are to be placed, and wherein the step of indenting said workpiece is performed at said each of said locations sequentially.

69. The method as set forth in claim 57, wherein the step of indenting and the step of removing material from said workpiece are each performed two or more times.

70. The method as set forth in claim 69, further comprising a subsequent step of removing sufficient material from said workpiece to form a finished passageway defined by a finished wall edge portion.

71. The method as set forth in claim 67, wherein said step of simultaneously indenting said workpiece comprising acting on an obverse and on a reverse side of said workpiece.

72. The method as set forth in claim 69, wherein the first removal step comprising removing material to form a first hole portion having a dead end portion in said workpiece a first diameter, and wherein a subsequent indentation step comprising acting said indenter against said dead end portion of said first hole portion.

73. The method as set forth in claim 72, further comprising, after the step of acting said indenter against said dead end hole the step of removing material to form a second hole portion in said workpiece, said second hole portion of a second diameter, wherein said second diameter is smaller than said first diameter of said first hole portion.

74. A method for working a bounding portion of material adjacent a preselected location for a slot in the body of a workpiece, to create beneficial residual compressive stress in said bounding portion for improving the fatigue life of said workpiece, said method comprising:

providing an indenter, said indenter comprising a surface portion, said surface portion adapted to impact said workpiece at pre-selected surface locations adjacent said pre-selected location for said slot in said workpiece;

indenting the body of said workpiece at said pre-selected surface location of said workpiece with said indenter to provide an effective amount of beneficial residual stress compressive stress in said structure within at least a portion of said bounding portion of material in said body of said workpiece;

removing from said body of said workpiece a selected portion of material, said selected portion of material removed to define a bounding portion adjacent

a slot created by removal of said material, said material removed comprising at least a portion of said workpiece having been impacted by said shaped surface portion of said indenter, so that at least a portion of said bounding portion of said body of said workpiece material exhibits residual compressive stress.

75. The method as set forth in claim 74, wherein said workpiece comprises a blank for an article of manufacture selected from the group comprising (a) gears, (b) turbine rotors, and (c) shafts.

76. A method for working a bounding portion of material adjacent a preselected location for an opening in the body of a metallic portion of a composite workpiece, said composite workpiece of the type comprising a sandwich material having a metallic layer and a composite layer, to create beneficial residual compressive stress in said bounding portion for improving the fatigue life of said workpiece, said method comprising:

providing an indenter, said indenter comprising a surface portion, said surface portion adapted to impact said workpiece at pre-selected surface locations adjacent said pre-selected location for said opening in said workpiece;

indenting the body of said workpiece at said pre-selected surface location of said workpiece with said indenter to provide an effective amount of beneficial residual stress compressive stress in said structure within at least a portion of said bounding portion of material in said body of said workpiece;

removing from said body of said workpiece a selected portion of material, said selected portion of material removed to define a bounding portion adjacent an opening created by removal of said material, said material removed

comprising at least a portion of said workpiece having been impacted by said shaped surface portion of said indenter, so that at least a portion of said bounding portion of said body of said workpiece material expands toward said opening.

77. Tooling as set forth in claim 36, wherein said first indenter further comprises a downwardly projecting centering punch portion.

78. Tooling as set forth in claim 36, wherein said second indenter further comprises a downwardly projecting centering punch portion.

79. The apparatus as set forth in claim 1, or in claim 7, wherein said indenter comprises comprises a lubricant coated surface, said lubricant coated surface adapted to decrease friction between said indenter and workpiece.

80. The apparatus as set forth in claim 79, wherein said lubricant comprises a dry film lubricant